Final Report submitted to NOAA's Human Dimensions of Global Change Research (HDGCR) Program

Decisions for Irrigation with Climate Fluctuation

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I. Preliminary Materials

A. Project Abstract

Based on previous work that has identified key water management strategies for irrigated agriculture, the project refined the process for conveying El Niño-Southern Oscillation (ENSO) forecasts for advanced planning of river management and irrigation seasons. We applied lessons learned by ourselves and by others in the NOAA HDGCR program on successfully using climate information to assist practical management of resources.

Scientist-stakeholder workshops were used as a format for vetting ENSO forecasts for use in advanced planning of river management and irrigation operations in the Yakima Basin of Washington State. Previous research has identified possible strategies for using long-lead forecasts of the climate state in the southern Pacific Ocean as a tool in planning for and reducing the impacts of periodic drought or floods. As has been observed in recent literature, the policy constraints imposed by water management institutions limit the use of long-lead probabilistic forecasts in major seasonal water supply allocation decisions. In the case of the Yakima Basin, the constraints imposed by the long-used, institutionally-imbedded, and conservative method of forecasting irrigation water supplies (Total Water Supply Available or TWSA) are compounded by physical "plumbing" constraints imposed by the physical layout of the basin, the location and type of water customers, and the location and condition of storage projects and water conveyance systems. However, the workshops identified ways long-lead forecasts can be used for significant secondary water management issues and as well as to condition use of the main TWSA forecast.

Using a reservoir model, historical analog water years, and probabilistic unregulated flow forecasts that vary by climate state, we derived pro forma state-dependent rules for reservoir operations that satisfy flood control, irrigation water availability (including crop production economics) and in-stream flow objectives. Modifying operating rules according to ENSO/Pacific Decadal Oscillation (PDO) state was expected to reduce the risk to junior irrigation interests facing specific levels of water prorationing, but is highly constrained by legal precedent and conservative institutional practice. We held a series of four intensive hands-on workshops with Yakima River basin stakeholders based on the principles of the convergence and collaborative learning approach for the purpose of information exchange and training in climate variability–sensitive water management and revealing participants' information preferences and use. Workshop participants were asked to analyze methods for coping with the climate forecasts, aided by the modeling tools. We collected data on the role of information in the planning and response process in the workshops, with probes based on the key issues identified in the literature concerning the use of scientific information and analysis in policy making and individual decision making. A significant take-away message from the workshops is that climate forecasts have limited ability to directly influence current major water allocation

decisions based on official forecasts, but can be used to condition these forecasts and to assist in several second-tier decisions on irrigation operations, as well as to help irrigators pre-plan for reactions to emerging drought.

B. Objective of Research Project

The objective of this project is to provide NOAA and the scientific and stakeholder communities, through a workshop format, with improved and detailed understanding of how climate variability information is assimilated by decision-makers to manage tradeoffs between irrigated agricultural interests and in-stream environmental demands. The proposed project also would refine the process for incorporating ENSO forecasts into advanced planning of water allocations at the project, district, and farm level before and during irrigation seasons.

C. Approach

A previous study found that some water–rights leasing strategies could be profitable to both the selling and purchasing farmer, even when confidence in the El Niño prediction is only as high as 70% (Scott et al. 2004). The approach in this project expanded on those findings by working on detailed water management strategies with the region's water managers, farmers, and, increasingly, fisheries interests. We believed that these same strategies would also prove useful if, as was the case in the 2001 water year, a relatively rare non-El Niño drought appears with significant advance warning. Since a severe El Niño–year drought developed toward the end of the period during which we conducted the workshops, we were able to investigate how the workshop participants viewed the drought in the context of climate variability and change and how they were proposing to deal with it.

We concentrated on creating specific robust water management strategies at the local level and on building local capacity to cope successfully with climate variability because water management decisions and institutions are largely local. We assessed the vulnerability of irrigation districts in the Yakima Valley in conjunction with a focus group of irrigators and water managers to determine what drought-mitigating strategies are feasible and what technical, economic, and institutional factors control those strategies. The overall objective was to work with stakeholders to create better, more permanent mitigation plans. We paid particular attention to "what ordinary people feel about risk that experts neglect."

D. Description of any matching funds used for this project.

There were no matching funds for this project. Stakeholders participated in the workshops at their own expense.

II. Interactions

A. Description of interactions with decision-makers who were either impacted or consulted as part of the study; include a list of the decision makers and the nature of the interaction; be explicit about collaborating local institutions.

Four invited workshops were held during the period from April 2004 through February 2005. The first two focused on climate variability and managing water supplies during forecasted drought. In the third and fourth workshops we also sought the participants' opinions and reactions to the use of information tools to project the impacts of climate variability, assess the impacts of climate change, and to provide examples of risk analysis, reservoir modeling, and crop production modeling.

The invitees were selected via an intentional (non-random) mutual and chained referral process. For each workshop, we began by providing information about the purpose and objectives of the workshop to a few key contacts in the basin, inviting them to participate, and asking them to recommend other key people to invite, as well as the names of alternative contacts if the named key individuals could not attend. For each workshop, we sought a group of participants who were considered by their peers to be knowledgeable about water management and allocation issues in the Yakima Basin and about local crop production, with the overall group representing a balance of viewpoints among water management officials, water end users (farmers and fisheries managers), and consulting experts. We also tried to ensure representation by water managers and/or users from both the upper valley and the lower valley, and by each of the main irrigation districts in the valley.

The participants came from a number of stakeholder organizations, which included Bureau of Reclamation, irrigation districts, private growers, fish and wildlife agencies, water management consultants, and the Yakama Nation. They presented their own opinions, not the official position of the agencies with which they were affiliated, and there was actually a considerable amount of consensus. Where there was a significant diversion of opinion or the information came primarily from one group of respondents only, that has been noted in the description of the discussion.

B. Description of interactions with climate forecasting community (i.e., coordination with NOAA climate forecasting divisions, the International Research Institute for climate prediction (IRI), regional or local climate forecasting entities, etc.)

No direct interaction.

C. Coordination with other projects of the NOAA Climate and Societal Interactions Division (i.e., other HDGCR, Research Applications, or Regional Integrated Sciences and Assessments projects)

There was some limited interaction with the Climate Impacts Group (CIG) at the University of Washington to discuss runoff risks in El Niño years and long-term trends in snowpack. We organized a session at the American Association for the Advancement of Science that discussed impacts of climate change that featured impacts of climate change on U.S. western mountain snowpacks critical to irrigated agriculture. This featured CIG findings. CIG findings on declining Cascade Mountain snowpacks presented at a meeting of the Washington State section of the American Water Resources Association also influenced the participants at our stakeholder meetings and provided a model for "how to think" about climate change impacts.

III. Accomplishments

A. Brief discussion of research tasks accomplished. Include a discussion of data collected, models developed or augmented, fieldwork undertaken.

As input to the four stakeholder workshops conducted as part of this study, we developed and demonstrated some simplified management modeling of the Yakima Basin. We have adapted or developed a series of simple software tools to calculate water availability, risk of irrigation water shortfalls, and effects on key crops' yields, farm profits, and the regional economy. We also have forecasted effects of climate change on natural flows in the Yakima River and have calculated the resulting impacts of weather and irrigation water availability on these same crops. We have examined some crop adaptation regimes with current cultivars and have looked at the consequences of additional water storage. We analyzed the consequences of water release policies and strategies with and without added storage but did not develop explicit new "rule curves" for operation of reservoirs or examine the effects of new crops or short-season cultivars.

To perform the formal analyses reported in this paper, we linked together four computer models. Roughly speaking, two of the models develop estimates of the supply of irrigation water in the basin, and the other two deal with the demand for water and the consequences if water is not available. The relationship between the models is shown in Figure 1.

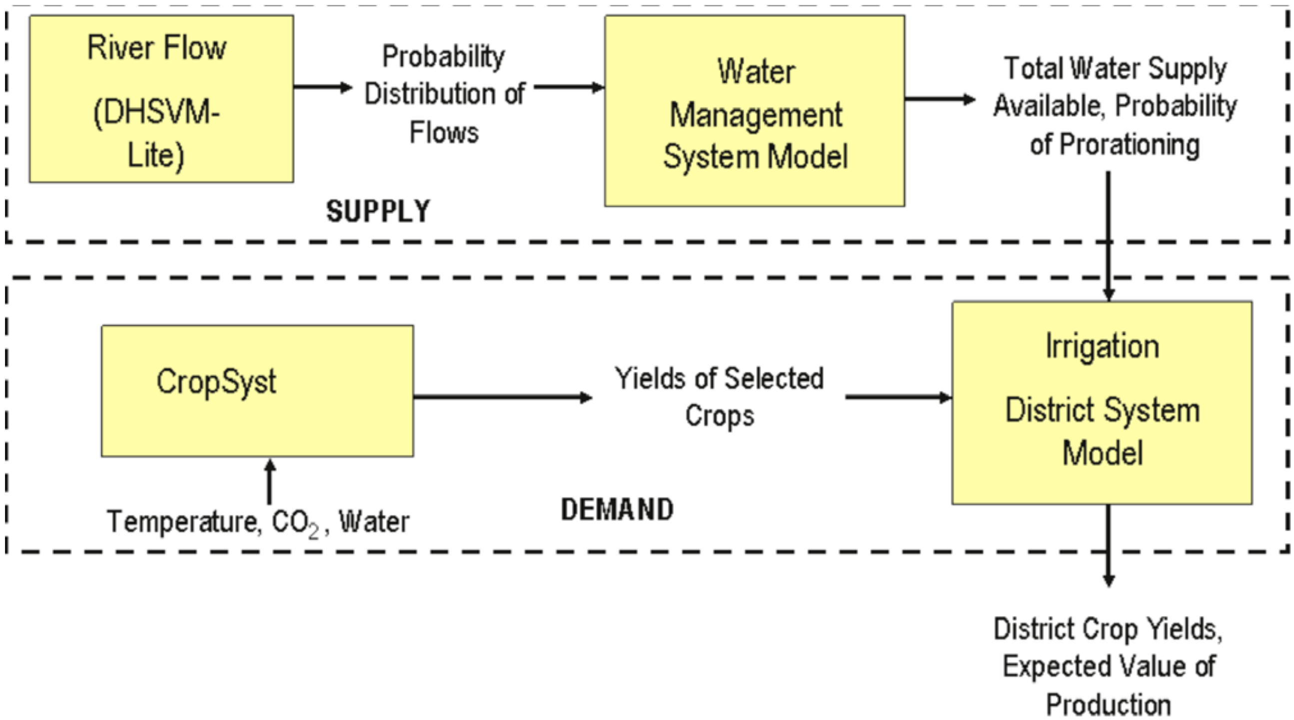

Figure 1. Models Used in the Analysis of the Yakima Basin Adaptation to Climate Variability and Change.

The first of the models is a simplified version of the Distributed Hydrologic Supply and Vegetation Model (DHSVM) (Wigmosta et al. 2002) called DHSVM-Lite, which we used to translate daily temperature and precipitation for the water years 1950 to 1999 and calculated natural runoff in the Yakima Basin by month at the subbasin level. Estimates of natural runoff by month allowed us to simulate monthly TWSA under a number of conditions, including isolating the subset of historical water years during which El Niño and La Niña influenced river flows, as well projecting monthly water flows with warmer temperature regimes that might be characteristic of future climate change in the region. In the model, climate scenario temperature and precipitation drive estimates of snowpack and runoff for the Yakima River's various subbasins. The simplified water management model shown in Figure 1 contains our best estimates of monthly inflows to reservoirs and monthly flows in the unregulated parts of the basin provided by DHSVM-Lite. In the simplified water management model (Figure 2), the five actual Bureau of Reclamation storage projects are modeled as a single reservoir, which ignores the single-project storage constraints and operational details of managing the five reservoirs of the real Yakima Basin Project, but it allows for more rapid and convenient analysis of large scale water issues in the basin, such as the loss of snowpack or changes in the intra-annual timing of runoff. The model manages flow at the critical Parker gauging station by monitoring projected unregulated flows and diversions and then releasing water from storage (or spilling water if inflows to storage exceed storage capacity) to satisfy: a) minimum instream flow (for fish), b) maximum instream flow (to prevent flooding), c) nonproratable diversions (senior water rights), and d) proratable diversions (junior water rights). The flow at the Parker gauging station does take return flow from upstream diversions into account. In preparation for the workshops, we ran this water management system model for the water years 1950-1999, in sequence, to allow for the bunching of multiyear high and low water periods, with an effort to minimize the amount of prorationing needed during the irrigation season (between April 1 and September 30) in each water year, subject to satisfying instream flow needs and providing carryover water for October irrigation.

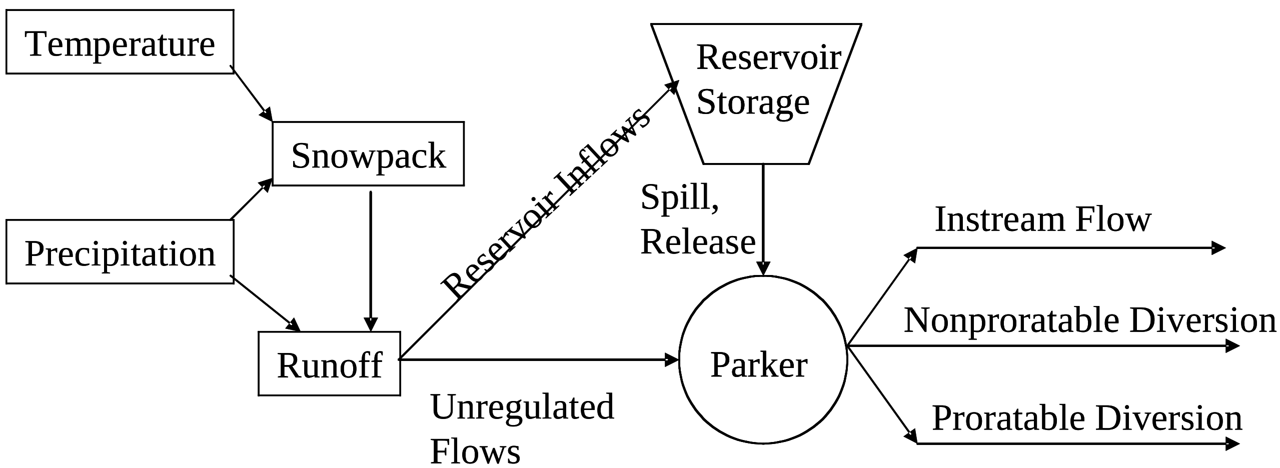

Figure 2. Simplified Yakima Basin Water Management System Model.

The third model used in the analysis is the CROPSYST model (Stöckle and Nelson 1996, 2003), which simulates the yield of crops grown under various climates, schedules of water availability, soils, crop pests, etc. Earlier analysis with this model in the Yakima Basin (Scott et al. 2004) showed that most crops have some tolerance for shortages of water (yield does not appear to decline significantly until shortages reach about 20%, meaning that water availability is at about 80% of normal). The losses become quite marked after about 30–40% shortfall. Besides the annual crops traditionally modeled in CROPSYST, two perennial crops, trellis-grown apples and cabernet wine grapes, were modeled for this study. All crops were modeled for current climate, for temperature increases of 2°C, 4°C, and 6°C, and for three transient climate scenarios with about 2°C warming in the years 2040–2060.

The fourth model developed for the analysis is an irrigation district crop yield simulation model previously used in two previous projects conducted by the research team in the Yakima Valley. It is adapted from a spreadsheet model developed by Northwest Economic Associates, Inc. (NEA) to calculate the impacts of periodic drought in the Yakima basin on the regional economy (NEA 1997), updated for 2000–2004 crop acreages by district, and for 2000–2004 average crop prices. The structure of this model is shown in Figure 3. The irrigation system model takes the estimate of prorationing for the junior water users estimated in the water management system model and reduced the production of each crop in each district from CROPSYST, according to the mix of crops in the district and the percentage of the crops grown by junior water users, and calculates changes in the amount and value of crops grown by irrigation district for various water shortfalls projected by DHSVM-Lite and the water management model.

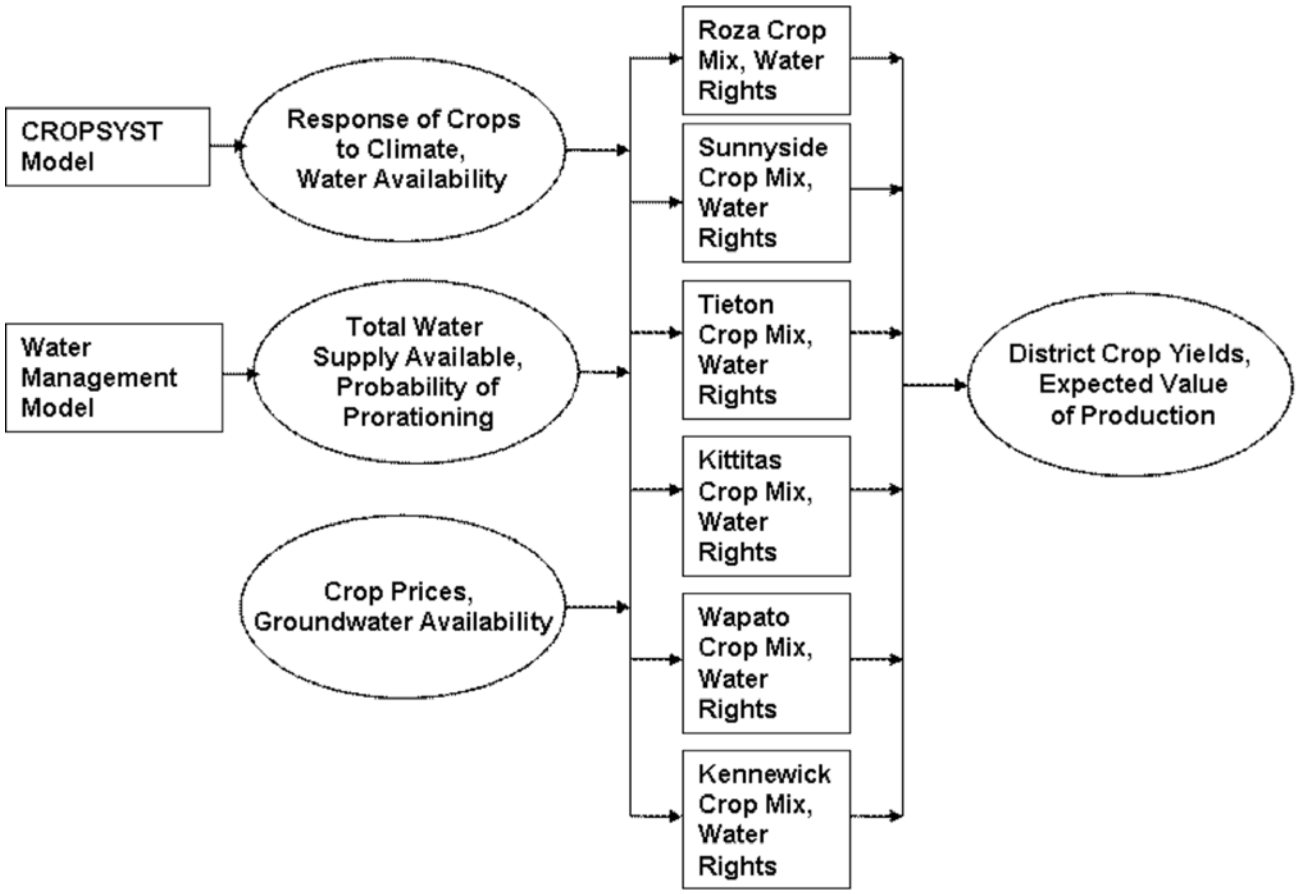

Figure 3. Yakima Valley Irrigation District System Model.

Finally, the four workshops produced a number of useful institutional insights that were recorded in workshop notes.

B. Key research results in bullet form.

Attached at end of report

C. Elaboration of key findings (i.e., how this research advances our scientific understanding)

The workshops tended to confirm previous observations in the literature concerning use of long term climate forecasts and climate change data.

Previous literature has found that barriers to forecast utilization exist due to 1) lack of ability by users to understand and apply probabilistic information, 2) lack of interpretation and demonstrated applications, 3) low forecast skill (real and perceived), and 4) low geographic resolution. We attempted a number of ways to show the impacts of climate variability and climate change on water available to agriculture in the Yakima Basin. Cumulative probability distributions, while appealing to hydrologists, climatologists, and economists, are not necessarily the best way to depict lower snowpacks. Color maps showing the extent of snowpack within the basin, together with probable water content seem to do a better job. Low forecast skill is definitely an issue with both water managers and farmers.

We attempted to translate risk information into a form that is directly relevant to decisions that can actually be made (Krantz 2001; Diop et al. 2001). The workshops seem to show that we have made progress in explaining the effects of climate change by using a combination of shifts in risk and historical analogs derived from El Niño-related drought. The high degree of complexity in the water management system requires specific system knowledge and highly disaggregated modeling to provide directly relevant information to water managers and farmers. Risk of low water availability is captured in the Bureau of Reclamation TWSA forecast, but because it depends on observed snowpack, the TWSA forecast is officially available only relatively late in the water year (April). Early and accurate prediction of TWSA could be helpful in decisions such as planting spring crops, purchasing water for irrigation, or "shaping" winter flow for salmon survival.

The workshops revealed several institutional, economic and "plumbing" constraints to water management in the face of drought under current climate. Among the relevant issues are that water that irrigation districts or landowners would like to trade cannot always be physically moved from one location to another within the Yakima Basin, that irrigation districts rather than individual farmers often have to be the parties that engage in the transactions to move water; that the 1945 Consent Decree and Washington water regulations place strong constraints on how water may be traded; and finally, that not all irrigation districts have close control over their water supplies.

Previous literature states that is important to convey the limitations of the forecasts in an understandable manner to manage expectations. People estimate risks in part by trusting or not trusting institutions (see also Stern and Easterling 1999; Glantz 1982). The most telling piece of data for the workshop participants on climate change was *historical observations on snowpack* now emerging from research at the University of Washington and elsewhere. It may be the equivalent of a "smoking gun." Consistent, multi-year interaction between researchers and regional stakeholders also appears to have contributed to increased credibility and confidence, as personal relationships and shared knowledge have been created between researchers and the key stakeholders.

Historical analogs concerning TWSA were a significant touchstone for workshop participants, whether in discussing the current severe drought that was then ongoing during the 2005 water year, climate variability generally (e.g., the impact of El Niño), or the effects of future climate change. Participants constantly referred to events and coping actions that happened during the previous two severe droughts in 1994 and 2001 and were able to reconstruct detailed descriptions of the parameters of specific "water years."

The participants gave every indication that they are most likely to use probabilistic information to condition historical knowledge, but are unlikely to shift the basis for decision-making without concrete evidence that the future will be different from the past, consistent with findings in NOAA (2000) and IRI (2001).

Long-standing agendas and frameworks that are tied to established funding criteria, agency evaluations, and constituency values, and therefore internal issue structures dominate thinking about resource management strategies and constrain response to new information. 1) The legal structure and precedent that has grown up around the implementation of the 1945 Consent Decree is so pervasive that the participants could not imagine a future circumstance so severe that it would not be followed. 2) The Bureau of Reclamation is strongly constrained in planning for future operation of the Yakima River for climate change by the fact that much of its budget comes from the U.S. Army Corps of Engineers for flood control. 3) Institutionally speaking, the Bureau of Reclamation is forced to take very conservative water management positions. This takes the form of statements such as "we do not release water that we don't have" or "we don't move water based on a forecast." Bureau of Reclamation water managers believe that they would be subjected to much stronger criticism if they tightened prorationing during an irrigation season in response to a deteriorating water supply situation (especially if they released water during the winter) than if they were overly conservative and eased up on prorationing during the season.

The mutual-learning workshop methods discussed by Covello (1992) and Walker and Daniels (2002) proved helpful in identifying and outlining four strategies that could be useful in addressing both the periodic droughts that cause serious economic losses in the Yakima Basin and the future prospect of more frequent and severe droughts due to climate change:

- Fix the water delivery infrastructure. Relatively small infrastructure projects could fix shortcomings in the current water delivery system that would wring additional services out of the current water supply and cope better with current shortages and imbalances in the current water supply.
- To the extent possible within the constraints of limited water delivery systems and prohibitions on adverse third-party effects, make water trades as convenient and inexpensive to execute as possible. This could be done by much aggressive early analysis, pre-planning, and pre-approvals of water transfers that could then be swiftly undertaken when needed.
- Return the river to its natural floodplain as much as possible to reduce the adverse water management impact of having to manage to prevent floods in years when drought is far more likely. If fewer significant parts of the historical flood plain did not have to be defended from flooding, this would give the Bureau of Reclamation broader scope to aggressively fill reservoirs rather than to draw them down in the winter, which could provide an additional margin of water supply for summer irrigation.

- Undertake modest in-basin surface water and groundwater storage projects in locations where refill ratios are favorable or timing of fill and release is favorable. At least some of these projects show favorable preliminary benefit-cost ratios.

The prospect of climate change means that the increased probability of summer drought could significantly change the economics of raising irrigated crops in the Yakima Valley. However, the water management and crop simulation tools previously used for analysis of interannual variability also work very well to evaluate policies to deal with climate change. First, the water system models show that the projected shifting of runoff in the basin into the winter season means either that 1) the agricultural interests on average would have to make do with about half the water they otherwise would have had available during the summer growing season, or 2) additional storage would be needed to hold back the runoff for the season in which it is used. Second, the crop models show that expected yields would be systematically lower with warmer climate, and that the risk of low yields would be much greater than under current conditions. For example, low water availability is more likely under climate warming (see Figure 5 in the graphics depicting key research results at the end of the report). While at 100% of normal water availability, the CO_2 fertilization effect approximately offsets the effect of warmer temperatures at full water availability, the effect does not offset the effects of lower water availability (see Figure 6 in the graphics depicting key research results at the end of the report). If more water does not become available in the summer (through more storage), the choices become those of further increasing the efficiency of application where still possible and more frequently trading water to where it is more valuable. This would, for example, include trades from low-valued crops to high-valued crops, and from agricultural uses to urban uses. Irrigators are already well down the road of increasing efficiency and already trade water to a limited extent during drought. Combining these strategies with storage could not completely prevent crop losses, but could be effective in blunting their impact, expected crop losses due to climate change by about half (see Figure 7 in the graphics depicting key research results at the end of the report), while still leaving water in the Yakima for instream priorities such as recovery of endangered and threatened runs of salmon and steelhead.

Conclusion

For irrigated agriculture, analytical tools developed to analyze business and public policy decisions under the uncertainty of current climate can be adapted to also offer analysis of response to climate change. Analysis is currently being done with these models to evaluate adaptation options for both climate variability and climate change. The stakes are high, since periodic droughts are more likely under global warming and are costly, but large-scale new storage is also expensive and out-of-fashion in the federal government, while it is probably beyond the means of private parties and all but the largest state governments. An alternative cost-effective approach is to combine several small-to-medium scale adaptations that could significantly reduce the damage of drought. Moreover, this study considered only current cultivars of current crops and made no allowance for additional efficiencies either in water conveyance or in on-farm water use, either of which may help reduce the consequences of drought. The stakeholders pointed out that making the necessary water efficiency investments also requires a degree of certainty of benefits that may not be forthcoming of periodic drought is severe and frequent enough. Coping strategies of all kinds turn out to be most helpful for middle-severity droughts—if droughts are mild (water shortfalls ~20%), little adaptation is necessary; if droughts are severe (~60% shortfall) coping is both expensive and ineffective. If the adaptations in this study were combined with 1) the lowest-cost projects to improve on-farm water utilization and efficiency of conveyance and 2) different cultivars of existing crops or new crops that were adapted to an earlier growing season or were more drought-resistant, then even more of the projected damage might be avoided. Whether a successful plan to cope with climate variability and long-term change can be crafted in the Yakima Valley depends on political will and cooperation among the parties as well as analysis, but the analytical tools are not a constraint.

D. List of publications and presentations arising from this project.

Publications:

Scott, M.J., L.W. Vail, K.M. Branch, and J.A. Jaksch. 2006. Utilization of Climate Forecasts for Irrigation Water Management. PNWD-SA-7395. Submitted to Journal of the American Water Resources Association. Battelle, Pacific Northwest Division, Richland, WA.

Scott, M.J., L.W. Vail, K.M. Branch, and J.A. Jaksch. 2006. Climate Change and Irrigation Water Management. PNWD-SA-7393. Submitted to Journal of the American Water Resources Association. Battelle, Pacific Northwest Division, Richland, WA.

Scott, M.J., L.W. Vail, R. Prasad. 2006. What Can Adaptation to Climate Variability in Irrigated Agriculture Teach Us About Dealing with Climate Change? PNWD-SA-7396. Submitted to Journal of the American Water Resources Association. Battelle, Pacific Northwest Division, Richland, WA.

Presentations:

Scott, M.J., L.W. Vail, R. Prasad. 2006. Managing Water for Irrigated Agriculture Under Extended Climate-Related Drought. PNNL-SA-49961. Presented to the Pacific Northwest Regional Economic Conference, Portland Oregon, May 11, 2006.

Scott, M.J., L.W. Vail, and R. Prasad. 2005. Managing Water for Irrigated Agriculture Under Extended Climate-Related Drought. PNNL-SA-47342. Extended Abstract Proceedings of the American Water Resources Association 2005 Annual Conference. (Cleve Stewart, ed.). Seattle, WA. November 7-10, 2005.

Scott, M.J., L.W. Vail, C.O. Stockle, and A. Kemanian. 2005. Impacts of Water Availability on Washington Agriculture in a Changing Climate. PNNL-SA-47128. Presented at the Fall 2005 Climate Change Conference, Seattle, Washington, October 27, 2005.

Scott, Michael J., Lance W. Vail, Claudio Stöckle, Armen Kemanian, Kristi M. Branch Rajiv Prasad, Mark A. Wigmosta, John A Jaksch. 2005. "Benefits and Costs of Options to Mitigate the Uncertain Effects of Climate Change on Irrigated Agriculture in the Yakima Basin. What Matters? What Doesn't?" PNWD-SA-6980. Pacific Northwest Regional Economic Conference, Bellingham, Washington, May 20, 2005.

Scott, Michael J., Lance W. Vail, Claudio Stöckle, Armen Kemanian, Kristi M. Branch Rajiv Prasad, Mark A. Wigmosta, John A Jaksch. 2005. Adapting Irrigated Agriculture to Climate Variability and Change. PNWD-SA-6743. Presented at 2005 AAAS Annual Meeting, American Association for the Advancement of Science, February 20, 2005, Washington D.C.

Scott, M.J., L.W. Vail, C.O. Stöckle, A. Kemanian. 2004. "Climate Change and Adaptation in Irrigated Agriculture–A Case Study of the Yakima River." In Proceedings of the UCOWR/NIWR Annual Conference, July 20-22, 2004, Portland, Oregon. PNWD-SA-6448. Pacific Northwest National Laboratory, Richland, WA.

Scott, M.J. 2004. Impacts of Climate Change in Pacific Northwest Agriculture. PNWD-SA-6499. Transportation and Climate Change Conference 2004, Seattle, Washington, May 18, 2004.

E. Discussion of any significant deviations from proposed work plan (e.g., delayed fieldwork due to late arrival of funds).

Scheduling the workshops to match the availability of the identified individuals proved to be a challenge. In an effort to minimize conflicts with invitees' other commitments, we scheduled the workshops before and after the irrigation season and avoided the winter holiday periods. However, the "off-season" for irrigation is also the "on-season" for water meetings, so we experienced several conflicts of meeting dates that cut attendance and that, in the end, we simply had to accept. This meant that the number of participants in each workshop was fewer than we had planned, ranging from 4 to 10. Although we had originally proposed to feature a role-playing exercise in which the participants would attempt to develop "best plans" for managing the Yakima River using a computer-based reservoir management tool, this exercise did not prove workable. In preparing the computer-based tool for the workshops, we gained a key insight about water management in the Yakima Basin (and perhaps elsewhere as well): there are so many detailed institutional and "plumbing" (water deliverability) issues in the valley that modeling them all was not practical within the resources of the project.[1] We decided that it would be more useful to discuss these issues directly and develop potential solutions to these constraints than to reflect their consequences in a computer-based model where they would be less obvious and notable.

IV. Relevance to the field of human-environment interactions

A. Describe how the results of your project have furthered the field of understanding and analyzing the use of climate information in decision making.

The existence of complex and detailed constraints means that as a practical matter it is costly for irrigators and water managers to take specific actions in response to seasonal forecasts of shifted risk of drought. As a result they tend to want short-range (maybe 10-day or 10-week forecasts rather than 10-year forecasts), highly reliable forecasts that would allow them to react to drought with high confidence, rather than more general probabilistic projections that primarily provide justification for anticipatory actions such as building storage projects. The institutions surrounding water use in the basin have long legal legacies and imbedded institutional incentives that mean climate forecasts may be used to supplement, but not supplant, current methods of forecasting water supplies. Bureau of Reclamation water forecasters already use seasonal forecasts informally to guide interpretation of their own, more conservative methodology. As experience confidence is gained, the use of seasonal forecasts may become more directly imbedded in the procedures used to determine Total Water Supply Available.

Despite the uncertainty of climate change forecasts, there is a clear emerging picture in this case study that the risks of lower water availability in the future are substantial for low-elevation snow-fed irrigation projects. Despite the uncertainties inherent in such projections, it is clear that the conflicts over water and the prospects for inadequate summer water are enhanced by the seasonal shift in runoff. The study investigated a number of actions that can be taken that would both reduce the vulnerability of such systems to current drought and to future climate impacts, and there are additional actions such as constructing additional, moderately-priced storage facilities that would further reduce vulnerability and which would have a positive benefit-cost balance.

B. Where appropriate, describe how this research builds on any previously funded HDGEC research (i.e., through NSF, EPA, NASA, DOE, NGOs, etc.)

Several studies have evaluated the use of information on climate variability in managing natural resources. Several of the “lessons learned” to date are captured in NOAA (2000)

[1] U.S. Geological Survey is in the process of developing a comprehensive computer model of the Yakima ground and surface waters that is expected to be sufficiently detailed to examine the physical tradeoffs in water management in the Yakima basin—e.g., the effects of reduced surface water diversions during drought on groundwater and base flow—but it is not yet completed

and IRI (2001) and can be applied to the Yakima River basin. Some key findings from the individual papers included:

- Barriers to forecast utilization exist due to 1) lack of ability by users to understand and apply probabilistic information, 2) lack of interpretation and demonstrated applications, 3) low forecast skill (real and perceived), and 4) low geographic resolution (NOAA 2000).
- Probabilistic information needs to be translated into a form that is directly relevant to decisions that can actually be made (Krantz 2001; Diop et al. 2001).
- Farmers (and other resource managers such as water managers) are often constrained by technical, economic, institutional (including legal), or other practical limitations in making use of climate forecasts.
- It is important to convey the limitations of the forecasts in an understandable manner to manage expectations. People estimate risks in part by trusting or not trusting institutions (see also Stern and Easterling 1999; Glantz 1982).
- Local knowledge systems or previous experience with official forecasts, differing economic objectives, and livelihood strategies all play a role in the acceptability of forecasts. Dates and types of key information must correspond to actual decision-making processes and should be sector-specific (see also Margolis 1997).
- Decision makers are most likely to use probabilistic information to condition historical knowledge, but are unlikely to shift the basis for decision-making without concrete evidence that the future will be different from the past.
- Long-standing agendas and frameworks that are tied to established funding criteria, agency evaluations, and constituency values, and therefore internal issue structures, can dominate thinking about resource management strategies and constrain response to new information.

Other literature provides similar lessons. The National Research Council (NRC) (Stern and Easterling 1999) provides an important summary of behavioral research on designing information delivery systems to make climate forecasts useful and relevant, given the mismatch between decision-making and forecasts mentioned above. In the context of the Yakima Basin, Stern and Easterling explicitly note the concern that adequate representations of accuracy and uncertainty must be provided with the forecasts to prevent water managers from inaccurately informing irrigators of coming water conditions that could lead them to make inappropriate, and costly, adjustments in their cropping strategies. Cases from the Yakima Basin in 1977 (Glantz 1982) and northeast Brazil in 1996 (Lemos et al. 1998) are cited. More generally, Stern and Easterling also emphasize the importance of forecast users' "mental models" of climate in their use or disregard of particular forecasts. Since people do not naturally think probabilistically (Gigerenzer and Hoffrage 1995), the risk communication literature emphasizes a cooperative learning approach between experts and the public (e.g., Covello 1992; Bradbury 1994; Peters et al. 1997; McDaniels et al. 1999; Gregory 2000; Walker and Daniels 2002) to promote better communication and understanding. This project is an exercise in cooperative learning using mutual learning workshops.

As noted in the elaboration of key findings above, many of these previous observations were confirmed in the study. However, we also observe that despite the issues raised by the literature, our stakeholders noted that, although physical infrastructure and long-standing legal institutions can indeed be serious barriers to direct use of NOAA's probabilistic forecasts for allocating water, there are opportunities to use the forecasts to modify or provide context for the main TWSA water availability projections used in the basin, as well as to guide lower-stakes water management decisions such as flow-shaping for fish.

It is clear that stakeholders in the Yakima Basin are becoming increasingly comfortable with water trading as a means to allocate scarce water supplies to its highest-valued uses during drought. However, the workshops also identified many serious physical constraints inherent in the hydrology of the Yakima Basin and the water-conveyance infrastructure that sharply limit the scope of water trading in response to drought, even when a coming drought can be projected with some certainty. Repairing and modifying the conveyance infrastructure in the basin would provide a measure of assistance in making a trading a more viable policy tool.

The workshops also identified several other operational uses for climate and weather forecasting in within-season operation and in planning for activities such as maintenance of the conveyance system.

C. How has your project explicitly contributed to the following areas of study?

1. Adaptation to long-term climate change

The project combined modeling and stakeholder interaction to identify strategies that were no-regrets or low-regrets strategies that did not involve wholesale changes in irrigated agriculture in a specific river basin; more broadly, the study demonstrated both the value and limitations of long range forecasts and intellectual tools currently used to manage water in a specific basin in the context of climate change. The project demonstrated that important insights could be gained from modeling the basin in a simple manner based on the existing "mental model" prevalent in the basin of historical analog water years, but using a shifted temperature and runoff regime. The analysis showed that moderate-sized storage projects were a feasible strategy, but that large-scale storage was not, even with much greater prospects for drought.

2. Natural hazards mitigation

Running the historical analog water years with a shifted temperature and runoff regime exposed the possibility of additional winter flooding. The stakeholders in the workshops noted that there would be additional flexibility in managing the river for summertime low flow if there were wider leeway to allow winter flooding. Returning parts of the Yakima River to its "natural" floodplain was identified as a desirable strategy both for mitigating the natural hazards currently involved with periodic flooding and for achieving more flexibility in water management for climate change.

3. Institutional dimensions of global change

As described in the findings sections above, the workshops confirmed that legal and institutional legacy and physical infrastructure constraints may mean that seasonal climate forecasts can be used only to supplement more traditional management methods, but that high-quality, early forecasts can be useful for managing certain operational risks under current climate variability. The same institutions have limited ability to manage water under a shifted climate regime, even with perfect knowledge of the change in water availability. The forecasting and management institutions will be presented with a greater challenge because snowpack will become a less reliable indicator of potential runoff. Over time, other methods likely will have to be employed. Early indications from running our simplified water system management model in uncertainty mode indicate that failing to take account of a shifted climate regime, even under uncertainty, can exacerbate the damage of climate itself.

4. Economic value of climate forecasts

The project directly demonstrated the value of additional moderate-sized water storage projects and shifts of water supply from low-value annual crops to high-value perennial crops under climate change. The expected value of crop losses was cut in half by the addition of storage and aggressive water trading.

5. Developing tools for decision makers and end-users

Prototype software tools were developed that allowed the user to examine different types of water storage and water release options and the effects on irrigation water availability for any historical water year and for future water years with modified flow regimes. For climate variability, the water management options was used with variable assumed advance warning of drought and flood conditions, and was used to examine the consequences of management errors concerning state of the climate. The model also was used to demonstrate the consequences of various kinds of water storage options for regional irrigated crop production and water management with current and future climates.

6. Sustainability of vulnerable areas and/or people

The project examined the impacts of climate change on water availability for proratable junior users. The results of that examination indicate that the junior water users, who are currently vulnerable to periodic drought, would be exceptionally vulnerable to shifted flow regimes in a warmer climate.

7. Matching new scientific information with local/indigenous knowledge

Much of the scientific information on current water availability, prototype software, and management options developed in this project was discussed at length in the four stakeholder workshops. The workshop reports recorded stakeholder perceptions and concerns, and among other things led directly to the use of analog water years (directly, to describe the effect of climate variability, or adjusted for climate change) as a means of communicating key messages to and from the local community.

8. The role of public policy in the use of climate information

The stakeholders in our workshops agreed that pre-season actions to prepare for water trading and institutional modifications to facilitate trading (such as pre-clearance of certain categories of trades) would be economically advantageous. Climate information also was demonstrated to be useful in the planning of long-term water resources. In particular, the project showed the value of re-shaping annual flow.

9. Socioeconomic impacts of decadal climate variability

Decadal climate variability was not directly addressed by the project.

10. Other (e.g., gender issues, ways of communicating uncertain information)

Uncertain information regarding climate was communicated as a shifted risk of severe water prorationing, which the stakeholders appeared to find most useful as statements like “With two-degree warming, the odds of having a severe drought like 1994 or 2001 shift from about 1 year in 7 to about 1 year in 2.” The underlying cumulative probability distributions from which such calculations are made do not appear to convey risk information as effectively.

D. Suggestions for Future Research: How could this research be applied/tested in other sectors or geographic areas? What are possible future collaborations with other government agencies or NGOs?

The methods used in this project include: a) DHSVM-Lite software to downscale and express climate change as shifts in the amount and timing of unregulated surface water runoff, which can be (and have been) directly used in other watersheds; b) CROPSYST crop growth software, which can be (and has been) applied to a variety of crops around the world; c) a simple surface water management model, which is particular to the Yakima basin, but which can be adapted to other basins or replaced by other models where these are more suitable.

Insights on the impact of climate change and uncertainty obtained from the relatively simple models used in this project can be made operational by validating them in the more complex river management models actually used by the Bureau of Reclamation to manage the Yakima River. Since there is an active project by the Bureau of Reclamation to examine the feasibility, benefits, and costs of storage options in the Yakima Valley, for which the impacts of climate change should play an important role, insights and lessons learned in this project could be applied directly to the storage studies.

V. Graphics -- Please include the following graphics as attachments to your report:

A. Graphic depicting the overall project framework/approach

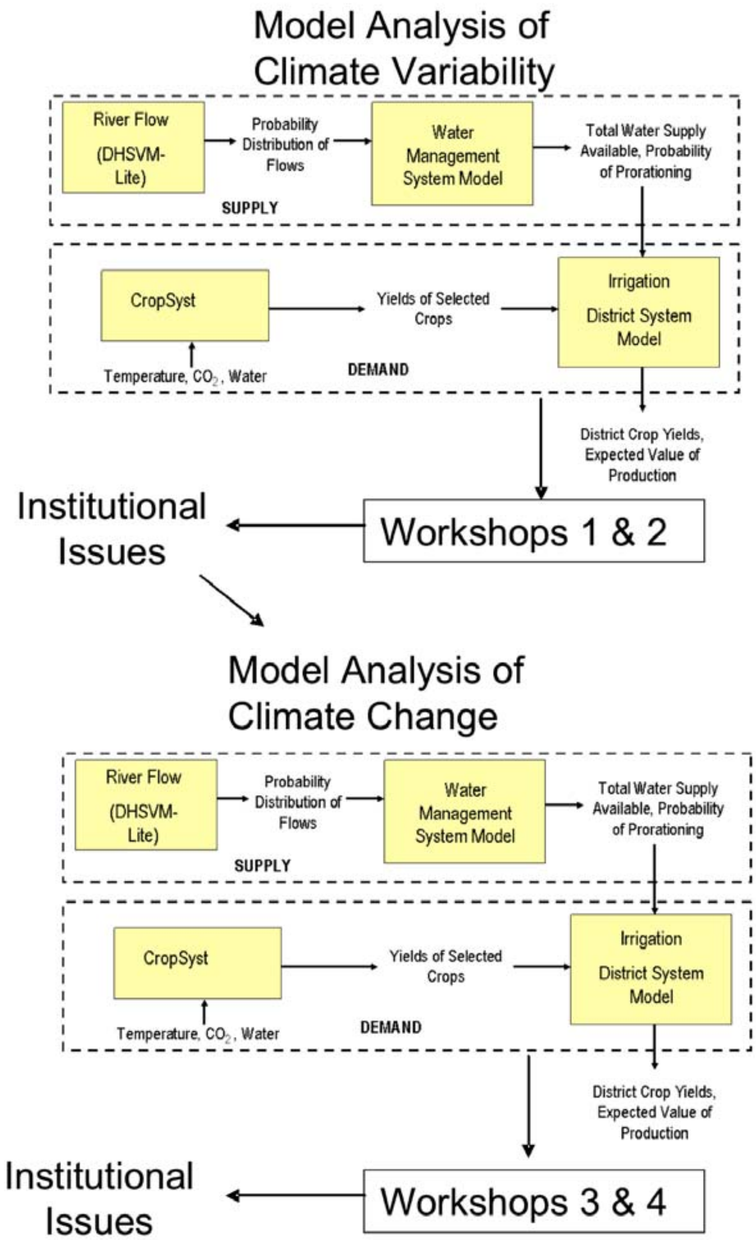

Figure 4. Analysis Framework and Approach for the Yakima Study

B. Graphic(s) depicting key research results

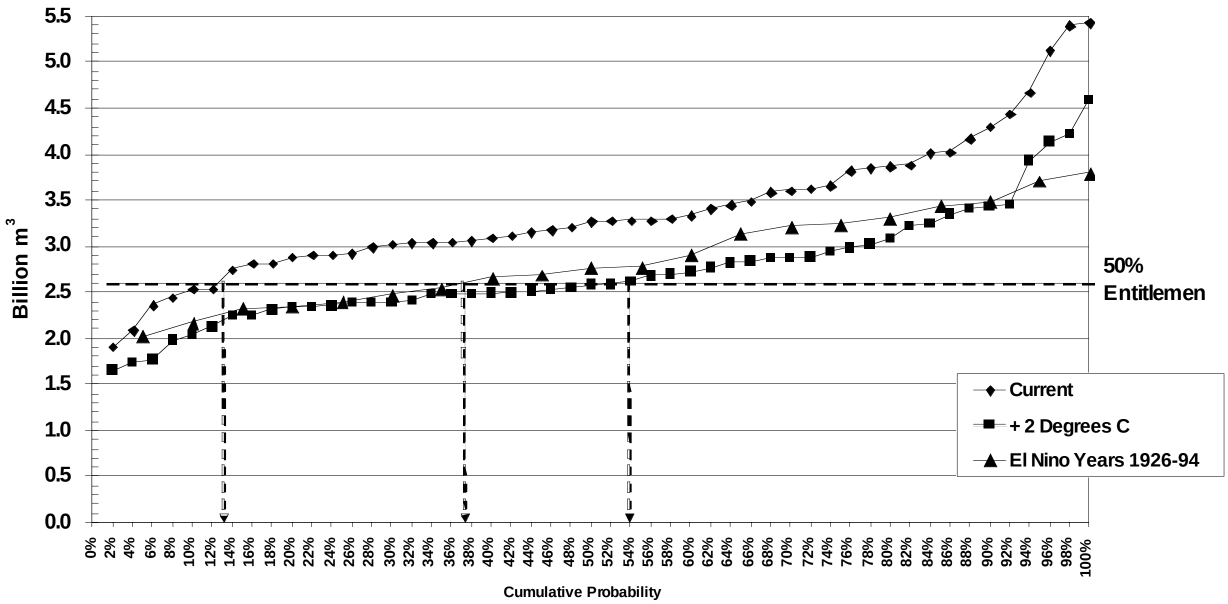

Figure 5. Cumulative distribution of Yakima Total Water Supply Available April 1-Sep 30 with climate warming, based on 1950-1999, average reservoir storage of 919 million m^3 (745,000 ac-ft) and minimum instream flows of 8.5 m^3s^{-1} (300 cfs), compared to El Niño years (current water demand assumed). Severe prorationing (50% water or less) occurs 14% of the time with current climate, 37% of the time in El Niño years, 54% of the time with 2°C warming.

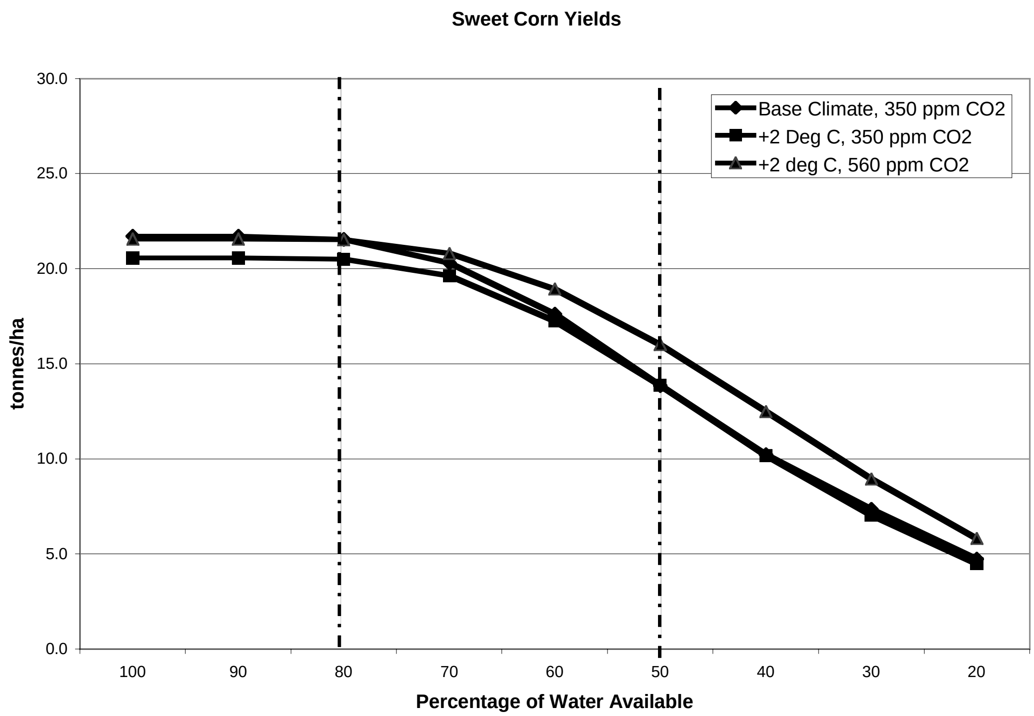

Figure 6. Illustration of typical crop yield impacts of climate warming in the Yakima Valley: the impact on sweet corn yields of 2ºC climate warming with and without CO_2 fertilization effects at various levels of seasonal water availability.

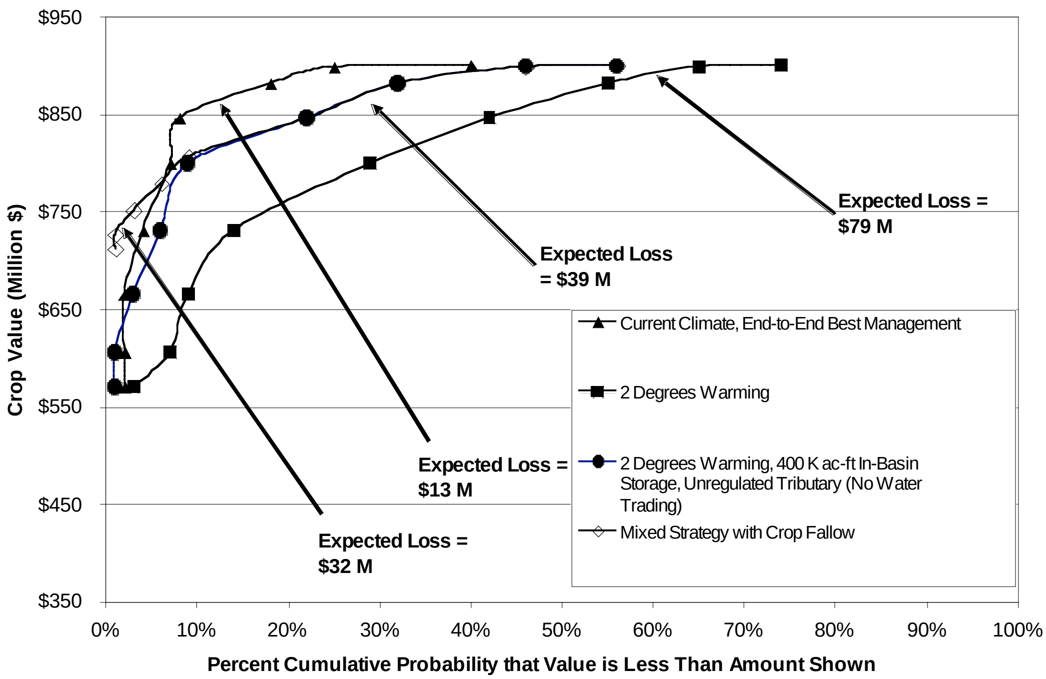

Figure 7. Cumulative probability of crop losses with 2°C warming, new in-basin storage, aggressive water trading from fallowed annual cropland, and "best reservoir management". Best reservoir management assumes water managers have perfect foreknowledge of the amount, timing, and location of runoff and manage the reservoir system to minimize the damages of low water availability, subject to the constraints of required instream flow.

C. Map of region covered by study (if applicable)

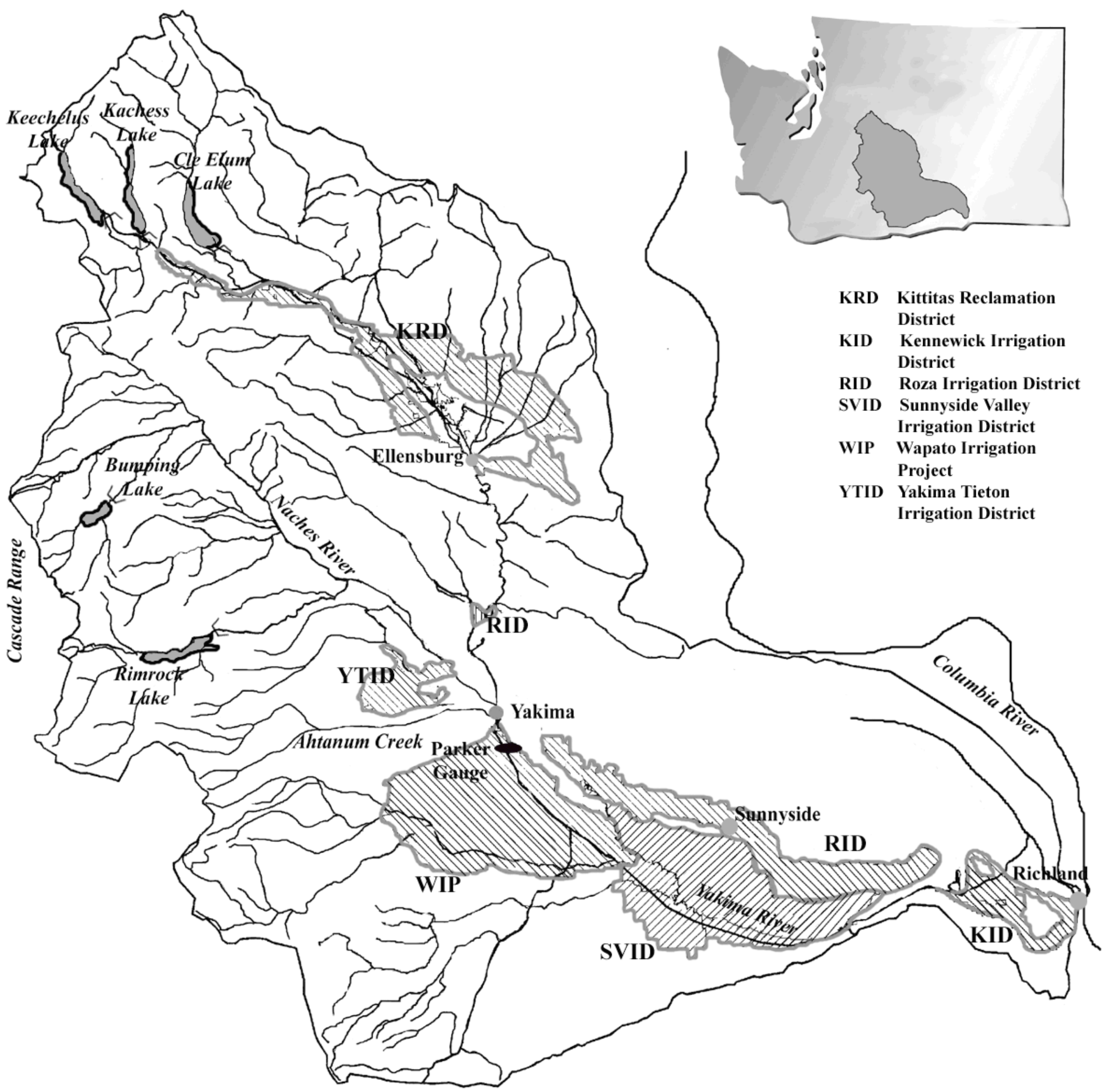

Figure 8. The Yakima River Valley of Washington State, showing Yakima Project Reservoirs and the 6 major irrigation districts (Source: adapted from Scott et al. 2004).

D. Photographs from fieldwork to depict study environment

None

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Attachment – Key Research Results

Low-Regrets Options for Irrigation Systems Dealing with Current Climate Variability and Climate Change

- Fix the water delivery infrastructure to improve control, eliminate waste.
- Optimize efficiency of on-farm water use
- Make water trades as convenient and inexpensive to execute as possible through early analysis, pre-planning, and pre-approvals of water transfers
- Return the river to its natural floodplain to reduce flood management burden
- Undertake modest in-basin surface water and groundwater storage projects in locations where refill ratios are favorable.
- Consider interbasin transfer if economic feasibility and environmental impacts allow.

Issues for Use of Climate Forecasts to Manage Irrigation Projects Confirmed in the Study:

- Barriers to use of climate-informed forecasts exist due to low forecast skill (real and perceived). Shifted risk predictions that are compatible with current or historical change in observed phenomena (e.g., declining snowpack) seem to carry the most weight
- Dates and types of key information must correspond to actual decision-making processes and should be sector-specific and application specific. Information considered too unreliable to guide overall water management can be used to guide lower-stakes operational functions such as water-shaping for fish, seasonal maintenance, or even water purchases
- Resource managers (such as water managers) are often strongly constrained by technical, physical, economic, institutional (including legal), or other practical limitations. Use of climate information must be adapted to address those limitations
- The limitations of the forecasts need to be conveyed clearly, and in an understandable manner, to establish credibility and manage expectations. Simple messages that are compatible with previous experience of the audience are most helpful
- Decision makers are most likely to use probabilistic information to condition historical knowledge, not replace it.

Conclusions

- Tools for irrigation water management under climate variability can be helpful for climate change.
- “Mental models” using historical analog years can be adapted to climate change and provide some useful results, but future climate will not look like exactly like analogs—which implies management risk and requires some formal modeling.
- More water storage would reduce impacts of shifted runoff patterns under climate change if well-planned, well-managed, and used with discipline, but modest-priced medium-sized projects may be superior to large projects.
- Risk-averse managing of reservoirs in future warmer climate reduces the number of really serious water shortfalls, but sometimes at the cost of more frequent smaller crop losses—more research is needed on this point.